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REPORT ON A PROPOSED NEW WATER STANDARD
IN WISCONSIN, WITH SPECIAL REFERENCE TO
ITS POSSIBLE APPLICATION TO THE MILWAUKEE
WATER SUPPLY

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September, 1938.

In a report (1) by representatives of the Wisconsin State Board of Health on an investigation of an outbreak of gastro-enteritis which occurred at Milwaukee in February, 1938, it was concluded, after reviewing extensive epidemiological evidence, that the outbreak was most probably water-borne and it was further recommended that a new standard of quality be adopted for chlorinated water supplies, with a view to preventing a recurrence of similar epidemics in the future. As the result of a controversy which developed between the State and local health authorities over this conclusion and recommendation, the present writer was detailed, in August, 1938, to study the proposed new standard with special reference to its possible application to Milwaukee water, and in this connection to review the laboratory results of examinations of this water.

During the week of August 15-20, 1938, the writer visited Madison and Milwaukee, Wisconsin, and conferred with the interested officials, who furnished him with certain pertinent data listed in an appendix of this report. Since returning to his regular station, the writer has studied these

data in considerable detail and has obtained through correspondence further information bearing on the interpretation of the data. Although he has not been requested officially to study the question of whether or not the outbreak of last February was water-borne, he has perforce considered this question to some extent in connection with his study of the proposed standard, which is understood to have been based in part on the observed variations in quality of the Milwaukee water supply during the period of the epidemic.

The proposed new standard contains four requirements, which in effect may be stated briefly as follows:

- (1) The chlorine demand of the water should not exceed 0.2 p.p.m. if a reasonable bacterial count in the tap water is to be maintained.
- (2) The residual chlorine in the water should at no time be less than 0.2 p.p.m., as determined after a 10-minute contact period with the testing solution at room temperature (20°C.).
- (3) The tap water bacterial counts at 37°C. should not exceed 50 per cubic centimeter.
- (4) The confirmed coliform index should not exceed 0.2 per 100 cubic centimeters.

In connection with the standard, several recommendations were made with respect to the laboratory control of chlorination, among which may be noted that tests for residual chlorine should be made at least every two hours throughout each 24-hour day, that tests for chlorine demand should be made in accordance with Standard Methods of the American Public Health Association, and that tests for coliform bacteria in the treated water should be made in 100-ml. portions along with those in 10 and 1-ml. portions. These recommendations are fully in line with the trend of best current practice in chlorination control and laboratory procedure, and in the particular case of Milwaukee might well be set as a minimum requirement.

The four requirements of the new standard may be considered from two viewpoints: (1) their general reasonableness and adequacy for the purpose intended, and (2) the possibility of meeting them under various raw water conditions and methods of treatment. As the present discussion is directed mainly toward considering the possible application of the standard to Milwaukee water, the more general aspects of the standard and its applicability will be noted only incidentally, though they may be important if the standard should be more widely used, both in Wisconsin and elsewhere.

The first requirement of the standard limits the chlorine demand of a water to 0.2 parts per million. This requirement should be fairly reasonable if applied to the chlorine absorption as measured by the standard test, but would appear somewhat unduly rigid if applied to the difference between the chlorine added to the raw water and the residual chlorine in the treated water. On this latter basis, the effluents of several filtration plants known to the writer, taking their raw water supplies from the Great Lakes, probably would fail to meet the requirement, despite the fact that these effluents are generally of good quality and safely low bacterial content. The mere presence of chlorine-absorbing substances in the raw water, in amounts sufficient to reduce the chlorine added by more than 0.2 p.p.m., should not in itself condemn the effluent if the treatment is adequate to produce an otherwise acceptable water for domestic use.

At Milwaukee, this requirement would be essential if the chlorine dosage were held constant at a low marginal level, regardless of variations in the character of the raw water, as in this case any material increase in the chlorine demand would result in an immediate depression of the residual chlorine to an amount which might be insufficient for

proper disinfection. A study of the past laboratory record indicates that it has been the general tendency at Milwaukee to hold the chlorine dosage constant as above indicated, except on comparatively infrequent occasions when some extraordinary circumstance has necessitated increasing the dosage. Under these conditions, requirement (1) is a decided measure of safety, the need for which could be obviated to some extent by more systematic variation of the chlorine dosage so as to ensure a residual chlorine always in excess of a suitable minimum amount.

Requirement (2) of the standard fixes the minimum residual chlorine in the treated water at 0.2 part per million. This requirement, though perhaps slightly excessive for a well-purified filtration plant effluent, appears to be a very reasonable one for Milwaukee water under the present method of treatment, as a certain margin of safety is necessary in this case to afford adequate protection to water consumers. It is in fact the present writer's opinion that in so far as Milwaukee is concerned, a safer minimum in this respect would be 0.3 p.p.m. under present conditions of treatment. With the new filtration plant in service, 0.2 p.p.m. should be an ample minimum if postchlorination is continuous and, except during periods of disturbed raw water conditions, might be slightly reduced if taste and

odor complaints were common. In general, filtration plants located along the Great Lakes, when dealing with raw waters of about the same degree of pollution as at Milwaukee, have apparently been able to produce satisfactory effluents with chlorine residuals ranging from 0.1 to 0.2 p.p.m. In some parts of the country, a minimum chlorine residual as high as 0.2 p.p.m. would cause widespread taste and odor complaints among water consumers, though this difficulty has been offset in part by the use of chloramines and activated carbon.

Requirement (3) of the standard limits the 37°C. bacterial count to 50 per cc. in the tap water. If this requirement is intended for application to water in all parts of the distribution system, as its wording implies, it appears to be an entirely reasonable one, as a certain margin of allowable increase in the 37°C count between the treatment plant and the distribution taps would be necessary under summer conditions. If, however, it is intended for application only to the treated effluent at the plant, the upper limit thus named appears to the writer to be somewhat inconsistently high in comparison with that of the coliform group as stated in requirement (4). In general, it has been his observation that a treated effluent meeting a limiting standard of 0.2 coliform bacteria per 100 cc. would tend to con-

tain numbers of 37° plate-growing bacteria very decidedly lower than 50 per cc., except under somewhat unusual conditions such as might result from secondary growths of chlorine-resistant bacteria in filters or filtered water storage reservoirs. It may be said, in fact, that the average efficient water treatment plant of a given type could produce an effluent meeting requirement (3) from a more highly polluted raw water than would permit the delivery of an effluent meeting requirement (4).

Requirement 4, which limits the allowable number of coliform bacteria to a maximum not exceeding 0.2 per 100 cc., is perhaps the most important and in certain respects the most debatable feature of the standard. It represents a radical departure, in the direction of increased stringency, from hitherto widely accepted standards such as that of the U. S. Treasury Department for drinking waters served by interstate carriers. If based on thoroughly reliable observations, this proposed new requirement should be considered very seriously, in view of the implication which it conveys that previous standards like that above mentioned are not sufficiently rigid to afford adequate protection against certain water-borne diseases such as gastroenteritis.

The primary basis of the proposed requirement is that during the gastroenteritis outbreak at Milwaukee in Febru-

ary, 1938, the city tap water was shown by the routine tests made in the municipal water and health department laboratories to have contained numbers of coliform organisms far below the upper limit set by previous standards. In fact, the record of these tests shows a zero coliform index in the tap water throughout the entire month of February, except in a single sample in which the presence of this organism was detected at the health department laboratory. On this basis alone it might be argued that a limiting standard of 0.2 per 100 cc. would afford no more absolute protection against gastroenteritis than a standard of 1.0 per 100 cc., except in a certain degree, as both standards apparently were met by Milwaukee water during the February epidemic.

In fixing the limiting coliform maximum at 0.2 per 100 cc., it seems to have been reasoned, however, that as this is about the lowest number of coliforms detectable in water by present routine methods, it would represent the safest practicable requirement short of specifying absolute freedom from any demonstrable trace of coliform bacteria (i.e. a zero coliform requirement). The major debatable point here involved is whether the evidence thus far available, at Milwaukee or elsewhere, would appear to justify increasing the rigidity of the coliform requirement in itself beyond that which is now fixed by hitherto accepted

standards, or whether further evidence should be sought, both as to the significance of the coliform group and to that of other groups of bacteria in the causation of water-borne outbreaks of gastroenteritis, before attempting to reformulate a standard expressed in terms of the coliform group alone.

In endeavoring to throw some light on this question, the present writer has studied in detail the results of water examinations at Milwaukee since the beginning of 1936, (5) during which period at least three recognized outbreaks of gastroenteritis have occurred at Milwaukee (including a reported outbreak late in August, 1938). In this connection he has also considered other data, such as previous records of laboratory examinations at Milwaukee (1928-30) (4) and also at Chicago, (6) where the treatment and character of raw water are practically identical with those at Milwaukee. He further has weighed certain evidence such as that which was brought out recently in a report by the Minnesota State Board of Health on a typhoid fever epidemic at Minneapolis in 1935.

From a study of the Milwaukee record during the period 1936-38, three significant facts stand out, namely:

(1) The numbers of confirmed coliform bacteria recorded in the treated water have shown no correlation whatever to any other indices of pollution in the raw or treated water, nor have they given any indication of unusual tap water conditions which might account for outbreaks of gastroenteritis such as occurred in February, 1938, and are said to have prevailed during January-March, 1936.

(2) On the other hand, the concurrent numbers of gas-former organisms in the treated water have shown a marked degree of correlation to all of the other indices of pollution, except the treated water coliforms, and during the epidemic of last February gave evidence, both by their high average level and by their tendency to vary roughly in accordance with numbers of reported new cases of enteritis, of unusual conditions affecting the quality of the tap water which might have borne some direct relation to the epidemic.

(3) The percentages of confirmed coliform bacteria recovered from presumptive tests have been almost uniformly high in the raw water, but extremely low in the treated water, in the latter case usually ranging less than 1 or 2 per cent.

The failure of the confirmed coliform bacteria to show some degree of correlation to other indices of raw and

treated water pollution during this period is difficult to explain, in view of the evidences of such correlation which have been brought out by the records for some of the years previous to 1936. Thus in Figure 8 of Mr. Schwada's paper⁽⁷⁾ before the American Public Health Association in October, 1935, he shows that a curve of monthly average coliform numbers in the tap water, over a seven-year period, 1924-30, tended to follow rather closely corresponding curves for the turbidity, per cent of gas-formers and 37° bacterial count in the tap water. In a report made in 1931,⁽⁴⁾ the present writer showed that during the years, 1928, 1929 and 1930 the numbers of coliforms in the treated water were closely related to variations in the corresponding numbers in the raw water, so that a plot of this relationship could be readily drawn (see Table 3 and Figs. 6 and 7 of the report). Although it is understood that since 1936 the confirmatory tests for coliform bacteria in the treated water have been slightly modified, it hardly would seem likely that this alone could explain the marked reduction in confirmed results during periods of disturbed raw water conditions noted during the past few years. Moreover, no radical change in the method of chlorination or in its laboratory control has been indicated by the record, sufficient to account for this change.

The close correlation above noted between variations

in the numbers of gas-formers in the treated water and certain other indices of pollution is consistent with that which has been shown in periods antedating the year 1933. Evidences of this correlation were thus shown in Schwada's paper⁽⁷⁾ and the present writer's 1931 report.⁽⁴⁾ A very striking indication in connection with the enteritis outbreak of last February was the close correlation observed between day-to-day variations in the gas-former index and the 37° bacterial count in the treated water and the general correlation between those two variables and the incidence of new cases of enteritis.

The extremely low percentages of confirmed coliform results obtained at Milwaukee in the examination of the treated water are considerably at variance with the corresponding results obtained, both at Milwaukee in the years 1923-30, and at Chicago where according to published results the percentages of confirmations have averaged 30 per cent or more as compared with less than 1 per cent at Milwaukee. It is difficult to explain this wide divergence on the ground of any known difference existing in the method of treatment or character of raw water, either at Milwaukee since 1930, or at Chicago where both the treatment and raw water are practically the same as at Milwaukee. It also may be noted that the percentages of B.coli confirmations at Milwaukee

have been decidedly lower than observed in general elsewhere in treated waters of the same character.

In this connection, it has been noted that in many instances the actual numbers of nonconfirmed coliforms in the treated water at Milwaukee have been ^{higher} than their corresponding numbers in the raw water, as shown by the difference between the numbers of gas-formers and confirmed coliforms in the two waters. A particularly striking example is indicated by the average results for March, 1936, which after minor M.P.N. correction were as follows:

	Numbers (M.P.N.) per 100 cc.		
	Raw	Treated	
	North Point	North Point	Riverside
Gas-formers	95.4	12.6	13.7
Confirmed	<u>92.7</u>	<u>0.14</u>	<u>0.26</u>
Difference (nonconfirmed)	2.7	12.5	13.4

In view of the short interval of flow time elapsing between the points of collection of the raw and treated water samples and of the fact that chlorination alone brings about no modification in the character of the water except its

living bacterial content, the nearly five-fold increase in the numbers of nonconfirmed coliforms shown in the treated water is difficult to explain, either on the ground of secondary multiplication of bacteria in this group or on that of a selective action by chlorine on the different strains of gas-formers present in the raw water. If nontypical spore-forming or other chlorine-resistant strains were a major factor in the situation, it is hardly conceivable, if the figures are correct, that the actual numbers of these organisms could show an increase of roughly 10 per 100 cc. in the treated water.

The possibility is suggested by these results, either that the routine tests in the treated water have failed to reveal the true numbers of typical coliforms present, or that chlorination may tend to modify some of the more resistant coliforms so that they appear as atypical forms in the treated water. Either one of these two hypotheses would explain both the apparent increase in the numbers of nontypical coliforms in the treated water and the abnormally low percentages of gas-formers confirmed as typical coliforms in this water. Until further light can be thrown on this question, it would seem unwise to use the confirmed results of this character as the basis of a new water standard, in view of the uncertainties surrounding their inter-

pretation. It is quite possible, in fact, that if improved methods could be devised for the more accurate quantitative determination of typical coliform bacteria in chlorinated effluents, or if the real sanitary significance of the preponderance of nontypical strains in such effluents were more definitely established, any revision of the present coliform standards either might be unnecessary, or would be carried out along quite different lines. In the meantime, more attention might very well be given to the possible importance of the nontypical gas-formers in chlorinated waters such as at Milwaukee, and especially to the significance of any abnormal increases in the numbers of these organisms during periods of disturbed raw water conditions.

The second phase of the question presented for study in connection with the proposed new standard is that which is concerned with the ability of the present chlorination plant and of the new filtration plant to produce an effluent meeting the requirements of the standard. Although the present chlorination system is expected to be superseded by the filtration plant at an early date, its limitations in meeting the new standard may be of interest because of the possible application of the standard to other sewage-polluted waters treated by simple chlorination.

In a recent report⁽²⁾ on an epidemiological study of

the enteritis outbreak of February, 1936, Dr. Krumblegel of the Milwaukee Health Department has shown (Tables 13-24) the times during the five years 1933-37 when the treated water at the Riverside station would have failed to meet one or more requirements of the new standard. His data indicate that during this time, if boiling orders had been issued whenever the standard was not met, these orders would have been necessary on 47 different occasions, aggregating a total period of 587 days, or roughly one-third of the entire period considered. A large proportion of the failures listed resulted from failure of the water to meet requirement (1) of the standard, limiting the chlorine demand to a maximum of 0.2 p.p.m. In this case the demand was figured as the difference between the chlorine added to the raw water and the residual amount in the treated water.

Dr. Krumblegel's tables apparently do not indicate the failures to meet requirement (2), limiting the residual chlorine to a minimum of 0.2 p.p.m. A study of the daily record since the beginning of the year 1936 shows that in months of relatively stable raw water conditions these failures were comparatively infrequent, but that in certain other months of disturbed conditions they occurred quite often. In a few highly disturbed months such as April, 1937,

the residual chlorine was less than 0.2 p.p.m. during a large proportion of the time. If routine tests for residual chlorine were made only twice daily, as the record indicates, they probably would fail to show some lapses occurring for periods of a few hours or less. Where recorded, most of the failures in meeting this requirement appear to have coincided with marked increases in the amount of chlorine absorbed by the raw water, when not sufficiently compensated by increasing the chlorine dosage above a normal level which appears to have been held at 0.42 or 0.48 p.p.m.

According to Dr. Krumbiegel's tables, the treated water at the Riverside station failed on 24 days to meet requirement (3) of the standard and on 12 days to meet requirement (4), the latter as indicated by the results of confirmed B.coli tests. If the B.coli confirmations had been as high as 10 or 20 per cent, which would be lower than the average at Chicago, the frequency with which the water would have failed to meet requirement (4) would have been very considerably greater.

Further evidence concerning the degree to which the water produced by the present chlorination system would be expected to meet requirement (4) of the new standard is afforded by a relationship plot shown as Figure VI in a report on an investigation of the Milwaukee water supply made by

the present writer in 1931. In this plot, based on the recorded performance of chlorination at Milwaukee during the three years 1928-30, it is shown that in order to allow the production of a treated effluent containing numbers of coliform bacteria not exceeding 0.2 per 100 cc., the raw water as delivered for treatment should contain numbers not greater than 6 per 100 cc. as an average. This represents an efficiency of 97 per cent B.coli removal, which is reasonably high for simple chlorination of raw Lake Michigan water. Incidentally, the plot above noted, on which this estimate is based, follows very closely the trend of similar relationships established previously by the U. S. Public Health Service from extensive observations elsewhere. (8).

For the purpose of rough estimate, it might be assumed that the present chlorination system at Milwaukee is sufficiently more efficient than the average system to be able to meet requirement (4) of the proposed new standard with numbers of coliforms in the raw water ranging as high as 10 per 100 cc., taking into account any improvements in operation effected since 1931. On this basis, a review of the laboratory data for the year 1936 has indicated that during the period of January-October, inclusive, for which raw water results were available, the system would be considered as having been overburdened on 125 of the 305 days

included in this period because of raw water coliforms exceeding 10 per 100 cc. in numbers. This would represent about 40 per cent, or slightly more than one-third, of the period considered, a figure which agrees quite closely with Dr. Krumbiegel's estimate of the proportion of the time during the years 1933-37 when the treated water would have failed to meet the standard.

If the new standard were to be applied at Milwaukee following the improvement in treatment facilities to be provided by the new filtration plant, the situation would be altered very materially, though the possible effect of certain requirements of the standard cannot be dismissed without some consideration. If the chlorine demand should be measured as the difference between the added and residual chlorine, as assumed in Dr. Krumbiegel's tables, it is entirely possible that at certain times of disturbed raw water conditions the total amount of chlorine absorption with prechlorination in effect would be little different under the same conditions from what it has been in the past. With postchlorination alone, the absorption would be materially less, though the records of several filtration plants along the Great Lakes have shown amounts in excess of 0.2 p.p.m. when the final effluent has been of wholly satisfactory quality, bacterially and otherwise. With the several lines

of defense available in modern filtration processes, this limiting chlorine demand requirement probably would be less important than in connection with simple chlorination, though with raw water as highly variable as at Milwaukee, frequent standard tests for chlorine demand would be an essential measure for controlling properly the chlorine dosage at different times.

With a well clarified effluent of more nearly constant physical and chemical quality such as will result from the new filtration plant, the necessity of maintaining high chlorine residuals in the finished water will be somewhat reduced, though a lower limit of 0.3 p.p.m. would be desirable if within the tolerable limit of chlorinous tastes and odors. If ammonia-chlorine treatment should be used as a finishing process, it might even be advisable to increase the minimum residual at the plant to at least 0.3 p.p.m., assuming that a sufficient period of contact were available to allow for the slower bactericidal action of chloramine as compared with that of chlorine alone.

In so far as meeting requirement (3) is concerned, no difficulty should be experienced with the new filtration plant under any raw water condition which is likely to occur, as observations elsewhere have indicated that the average efficient plant of this type should be able to produce an

effluent containing not more than 50 bacteria per cc., as determined by the 37° plate count, from raw water containing numbers ranging as high as 20,000 or 30,000 per cc. Exceptions to this rule might occur if secondary growths of 37° plate-growers should take place occasionally in filters or filtered water storage reservoirs, as sometimes happens during the warm season. Under these conditions, the 37° count in the effluent might exceed 50 per cc. regardless of the count in the raw water, if a considerable proportion of these bacteria were chlorine-resistant. A similar phenomenon also could occur in the water distribution system, if chlorine residuals were not sufficiently high to keep down secondary growths. In such circumstances, a detailed survey would show whether or not this condition were one of any sanitary significance, though it usually is not considered so if no secondary source of contamination is possible.

With reference to requirement (4), extensive observations⁽⁹⁾ by the U. S. Public Health Service have indicated that in order to produce an effluent containing not more than 0.2 coliform bacteria per 100 cc., the average Great Lakes filtration plant with postchlorination included should be supplied with a raw water containing not more than 100-200 coliforms per 100 cc., though with prechlorination added to this treatment, it has been estimated from other observa-

tions (10) that the permissible raw water maximum for Great Lakes plants could be increased to about 1500-2000 per 100 cc. without impairing the quality of effluent below that of requirement (4). This higher limit appears to fall above that which would be reached in the Milwaukee raw water except under extraordinary conditions such as prevailed in February, 1938, though for this exceptional reason it could not be said to mark a safe limit at all times or under all possible conditions.

The foregoing considerations would seem to lead to the conclusion that under present and past conditions of water treatment at Milwaukee, the tap water resulting from simple chlorination would be expected to fail in meeting the proposed new standard during a considerable proportion of the time, but that after the new filtration plant has been placed in regular operation, no difficulty should be experienced in meeting the standard except possibly under some extraordinary conditions such as prevailed during February, 1938, when the coliform index of the raw water exceeded the limits above stated on two days. If conditions of this kind could be anticipated and the treatment adjusted accordingly, it is quite possible that the new filtration plant could meet even such an unusual condition as that of last February without producing an effluent failing to meet the new

standard, though this question depends so much on future developments that it would be rash to attempt any definite prediction at this writing.

Although the commendable purpose of the proposed new standard is evident, the writer feels that it rests at present on a foundation which might well be strengthened by further and more precisely controlled observations. Moreover, in so far as protection against water-borne gastroenteritis is concerned, it is subject to the possible weakness of all existing water standards in that it attempts to limit by indirect means the specific causative element in these outbreaks, which at present seems to be unknown. If, as some presumptive evidence suggests, outbreaks of this character may be of bacterial origin and due to a chlorine-resistant organism of the gas-former type but not typically coliform, then a far greater significance should be attached to the presumptive gas-former index in water supplies suspected of being involved in such outbreaks than heretofore has been accorded to them. If, on the other hand, they may result from some conditions of pollution associated with the presence of extremely small numbers of coliform bacteria in a water, every effort needs to be made to increase the delicacy and reliability of routine tests for coliforms in treated waters and especially in those treated by chlorination.

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A thorough and painstaking study of the effects of chlorination on the cultural characteristics of the coliform group of bacteria, as well as other members of the gas-former group, in waters of various types subjected to ordinary chlorination, might throw considerable light on this question. So far as the present writer is informed, a sufficiently comprehensive study of this kind, using all of the resources of modern bacteriological technique, has not thus far been made.

In conclusion, the writer wishes to acknowledge the kindness of Messrs. L. F. Warrick and O. J. Muegge of the Wisconsin State Board of Health, for loaning him a large amount of pertinent reports and other data, to Drs. J. P. Koehler and E. R. Krumbiegel of the Milwaukee Health Department, for copies of their reports dealing with the epidemiological features of the gastroenteritis outbreak of last February, and to Mr. N. A. Thomas, Chief Chemist of the Milwaukee Water Department, for information concerning routine methods followed at his laboratory in testing Milwaukee water for coliform bacteria.

Respectfully submitted,

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